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In Vitro Study of the Effects of Nd:YAG Laser Probe Parameters on Bovine Oral Soft Tissue Excision

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Background and Objectives: **Lasers are now used for intraoral, soft tissue procedures. The effects of Nd:YAG probes on cutting efficiency and temperature rise were evaluated in vitro.**
Study Design/Materials and Methods: **Three hundred twenty-micron 400-μm, 500-μm, and 600-μm probes were used to ablate bovine gingiva, mucosa, and tongue at various power and frequency settings. Thermocouples positioned under the subjacent cortical bone measured temperature rise. Tissue samples were evaluated histologically.**
Results: **Mean pooled temperature rise was 1°C at 3 W and 1.4°C at 5 W. Excision width ranged from 0.63 mm to 0.79 mm at tested settings, cutting depths from 0.19 mm to 0.49 mm, lateral and deep coagulation from 0.27 mm to 0.62 mm.**
Conclusion: **Temperature rise in bone was related to increased power. Cutting efficiency of laser probes was not significantly improved by increased power. Probes of 320 to 500 μm provided efficient cutting at 3 W and 5 W, thus reducing the potential for unacceptable temperature rise in bone. Lasers Surg Med 20:39–46, 1997.** **© 1997 Wiley-Liss, Inc.**

Key words: dentistry; histology; laser in vitro study; laser parameters; soft tissue excision; thermal effects

INTRODUCTION

Lasers are becoming an increasingly important part of dental treatment. They are currently accepted for use in a variety of oral soft tissue applications and periodontal therapies. The pulsed, fiber optic-delivered Nd:YAG laser is approved by the Food and Drug Administration for incising, excising, and coagulating intraoral soft tissue, including marginal and interdental gingiva. These devices are used in dentistry for gingivectomy, gingivoplasty, soft tissue biopsy and lesion removal, soft tissue crown-lengthening procedures, and hemorrhage control. Specific indications for use are the cutting and coagulation of intraoral soft tissue, including the epithelial lining of the free marginal gingiva.

Nd:YAG lasers with high repetition rates have been developed to improve the efficiency of oral soft tissue surgery. Further, they are one of the few dental lasers with fiber optic delivery, facilitating easy access to all areas of the oral cavity. Nd:YAG lasers provide deeper and more uniform penetration of soft tissues than carbon dioxide or argon lasers because of the property of optical scattering, although tissue absorption of laser energy is relatively low [1]. Additionally, the short pulsed laser provides high peak power to reach the treatment objective without the buildup of excessive heat in the oral tissues. Even though Nd:YAG laser systems are generally considered to be slower than carbon dioxide lasers used for cutting procedures and have deeper extinction length (3 mm for Nd:YAG compared to 0.2 mm for carbon dioxide lasers) [2], Nd:YAG lasers offer clinical advan-

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tages due to the fiberoptic delivery, high pulse power, and short tissue interaction time.

The advantages of laser soft tissue surgery compared to scalpel wounds have been described [1,3–5]. Advantages include relatively bloodless surgery with little if any bleeding post-surgery; site-specific wound sterilization; minimal swelling and scarring; reduced necessity for suturing; decreased incidence of mechanical trauma; shorter operative time; favorable patient acceptance; decreased use of local anesthesia; and little or no postoperative pain. Additionally, bacteriological effects evaluated in vitro [6] and in vivo [7] demonstrated that laser treatment is effective in greatly reducing the number of cultivable bacteria.

Research on hard tissue application of lasers has studied thermal effects on dental pulp. Dental temperature change has been found to have a profound effect on pulpal tissue: A 5°C rise has been shown to cause pathologic changes in dental pulp [8–10]. Further, it has been demonstrated that as laser power increased, pulpal temperature rise occurred [11]. The temperature rise was thought to be the result of differing thicknesses of hard tooth structure, the enamel and dentin.

Remaining dentin thickness has been evaluated as a significant variable in our laboratory. Findings indicate that temperature rise through dentin thicknesses of 2 mm was limited and caused no pulpal damage at low wattage emissions (0.3 to 1.0 W). However, with thinner dentin surfaces greater temperature rises occurred [11]. Similar effects have been demonstrated in teeth treated with Erbium:YAG lasers [12]. It appears that higher power, increased repetition rate, and longer exposure time could result in unacceptable temperature increases in all exposed teeth, regardless of remaining dentin thickness.

All clinical dental lasers used in our studies have caused lower temperature rise of underlying bone compared to electrocautery when used on bovine oral tissues [13]. The maximum temperature rise in the bone was 5.5°C at 10 W using a 200-μm laser probe, while that of electrocautery was more than 10°C with a wide standard deviation [14]. This temperature increase explains why contact of an electrosurgery electrode to alveolar bone in dogs for any duration has been shown to cause necrosis of bone [15].

The purpose of this study was to evaluate the effects of varying Nd:YAG probe parameters on temperature of underlying bone tissue when oral soft tissues were ablated, using various power and frequency settings. In addition to temperature rise, the parameters of Nd:YAG laser probes for cutting and coagulation were determined and compared at various power and frequency settings.

MATERIALS AND METHODS

A free-running pulsed Nd:YAG dental laser with a 1.06-μm emission wavelength and full-width, half-maximum pulse duration of 150 μsec was used (Sunrise Technology, Fremont CA). Experiments were conducted on bovine tongue, gingiva, and oral mucosa that was acquired through the United States Department of Agriculture by application and permit. Tissues were obtained within 24 hr of animal sacrifice, from a meat rendering plant. The tissue specimens were stored during transit at 4°C and 100% humidity to prevent tissue degradation. Specimens were allowed to return to room temperature, 25°C, for no longer than 2 hr before temperature readings were obtained.

Temperature was measured by placing copper-constantan thermocouples beneath bone at a distance of 5 ± 0.5 mm from the surface of the gingiva and oral mucosal tissue. The thermocouples were placed in the medullary bone below the cortical plate. To ensure that the thermocouples were accurately measuring heat rather than laser energy, they were optically isolated with an opaque thermoconducting paste (Omegatherm "201", Stamford, CT). Thermocouples monitored temperature continuously before and during multiple excisions made on the gingiva using laser probe diameters of 320 μm, 400 μm, 500 μm, and 600 μm. Laser powers tested were 3, 5, and 10 W, with repetition rates of 10, 20, and 50 Hz. Laser energy parameters ranged from 60 to 500 mJ/pulse (Table 1).

The tissue specimens were ablated by an experienced operator at the rate of 2.5 mm per second and a force of 24 ± 9 g of pressure. The operator was trained to move the laser probe at a constant pressure across the tissue by practicing on a pressure sensitive platform. The operator then used the fiber optic hand piece to ablate the gingival tissue above the imbedded thermocouples. A separate sample of bovine tissue was ablated for each probe diameter at each power and repetition setting.

Following excision, the tissue specimens were prepared for histologic examination to determine cutting and degree of histologic coagulation, fixed in formalin, sectioned at 6 μm, and stained with hemotoxylin and eosin. The sections were

TABLE 1. Nd:YAG 150-μsec Pulsewidth Emission of 1.06-μm Emission Wavelength; Parameters Evaluated in the Study

Probe diameter	W	Hz	Energy/pulse (mJ)	Energy density (J/cm²)
320 μm	3	10	300	373
	3	20	500	621
	3	50	150	187
	5	10	250	311
	5	20	500	621
	5	50	60	75
	10	20	100	124
	10	50	200	249
400 μm	3	10	300	239
	3	20	500	398
	3	50	150	119
	5	10	250	199
	5	20	500	398
	5	50	60	48
	10	20	100	80
	10	50	200	159
500 μm	3	10	300	153
	3	20	500	255
	3	50	150	76
	5	10	250	127
	5	20	500	255
	5	50	60	31
	10	20	100	51
	10	50	200	102
600 μm	3	10	300	106
	3	20	500	177
	3	50	150	53
	5	10	250	88
	5	20	500	177
	5	50	60	21
	10	20	100	35
	10	50	200	71

taken from the middle of the cutting zone to ensure that each specimen represented the characteristics of that incision. Four specimens were measured for each laser parameter, and average values were calculated. A measuring microscope with 10× magnification was used to evaluate each sample. Measurements were made for the width and depth of the excision, as well as the lateral and deep thermal coagulation effects (Fig. 1).

The same procedures were carried out on bovine tongue to determine cutting efficiency, width, and depth. Tongue specimens provided better measurement characteristics than gingiva or oral mucosal tissues because the epithelium was thicker and not ablated entirely during the experimental incisions. Unlased portions of tongue served as controls.

Statistical analysis was performed using a multifactorial randomized analysis of variance

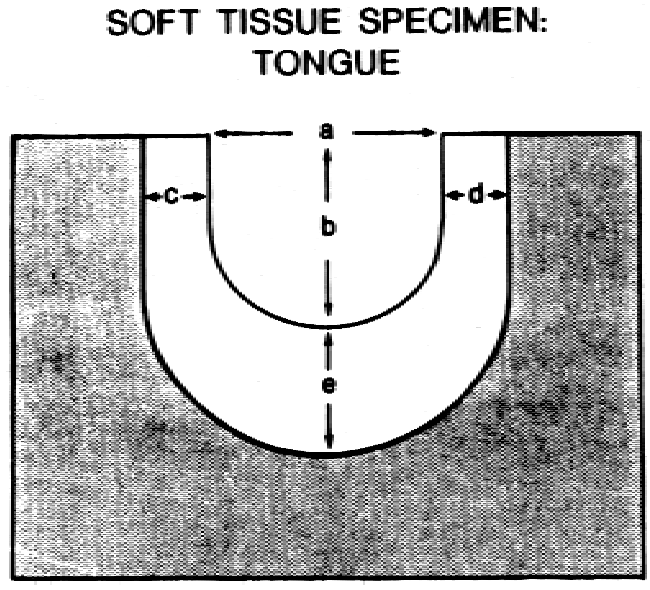

Fig. 1. Schematic representation of cutting and coagulation measurements (a = width of tissue removed; b = depth of tissue removed; c,d = lateral coagulation; e = deep coagulation).

with confidence intervals set at 95%. Student-Newman-Keuls post-hoc tests of significance were applied to the variables. Independent variables were probe width, power, and frequency. Dependent variables were depth of tissue removed, width of tissue removed, coagulation, and temperature measured in the medullary bone.

RESULTS

Temperature

Temperature results are presented in Figure 2. Variations in temperature rise recorded in bone were related to power. The temperature of the bovine tissue was 25°C during the experiments. The mean pooled temperature rise for all probe tips at 3 W and 10, 20, or 50 Hz was 1.0°C; at 5 W, temperature rise was 1.4°C, and at 10 W the rise was 3.0°C. Higher power resulted in higher temperature rises in the bone. There was no statistically significant effect of repetition rates on temperature rise (Fig. 2).

Histologic Evaluation

Examination of the laser excisions revealed both lateral and deep thermal coagulation histologic effects. Figure 3 is a representative histologic section of bovine gingiva after excision with 10 W, 50 Hz using a 320-μm-diameter probe in

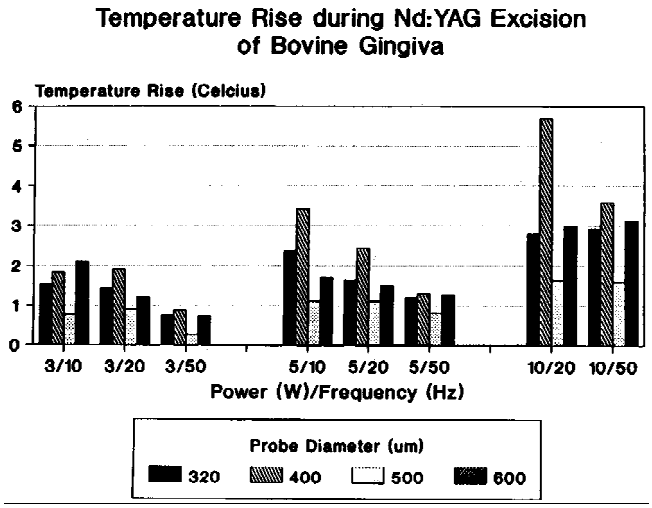

Fig. 2. Average temperature rise in underlying bone during Nd:YAG excision of bovine gingiva.

contact with the tissue. Epithelium was removed to the basement membrane with the width and depth of cut readily apparent. Histologic coagulation was present in the lateral epithelium and in a portion of the underlying connective tissue. The surrounding area adjacent to the cut and coagulation was histologically normal except for the tissue separation at the connective tissue interface (Fig. 3).

Cutting efficiency

Excision width ranged from 0.63 mm to 0.79 mm for all probe diameters regardless of the power and frequency used. The mean pooled effect at comparable energy densities for the tested probes was 0.63 mm for the 320-μm tip and the 400-μm tip, 0.79 mm for the 500-μm tip, and 0.77 mm for the 600-μm tip. Increasing the repetition rate had no statistically significant effect on laser cutting efficiency. Probe diameters provided cutting depths of 0.19 mm to 0.49 mm. The mean pooled cutting depths were 0.19 mm for the 320-μm probe, 0.42 mm for the 400-μm probe, 0.29 mm for the 500-μm probe, and 0.49 mm for the 600-μm probe. Higher-power (10 W) lasing with smaller probe diameters (320 μm) resulted in deeper cuts of 0.34 mm to 0.80 mm but similar widths when compared to other sizes of probes tested. These calculations were based on bovine tongue experiments because ablation of gingiva and oral mucosal tissues tended to penetrate entirely through the epithelium during experimental incisions.

Lateral and deep coagulation ranged from 0.27 mm to 0.62 mm for all probe diameters, with one exception. The 320-μm probe at 10 W and 50 Hz produced both lateral and deep coagulation of approximately 1 mm, 0.90 ± 0.21 mm, and 0.97 ± 0.16 mm respectively. Cutting width and depth, and lateral and deep coagulation made by probe tips of various diameters are presented in Figures 4–7.

There appeared to be a threshold energy density at which ablation would begin. For instance, ablation was variable at 3 W; bovine oral tissue was not penetrated at low repetition rates for the 320-μm and 500-μm probe tip.

DISCUSSION

Laser use for periodontal soft tissue surgery is known to be safe and offers some advantages over scalpel surgery. Surgery is possible with less bleeding, postoperative discomfort, swelling, pain, and achieves a sterilized surgical site [1,5]. It is important to characterize the specific effects of various powers, frequencies, and probe diameters on soft tissue excisions in order to apply Nd:YAG technology in the safest, most efficient manner.

Cutting efficiency required sufficient average power. At and below 3 W with low repetition rate, ablation did not occur reliably. This confirms our previously reported data that soft tissue cutting with Nd:YAG laser probes begins between 2 and 4 W regardless of repetition rate [14]. In addition, depth of the ablation was a function of average power, with width of the cuts remaining relatively constant for all the probe diameters. Incision width was remarkably similar for all probe diameters at every power and repetition rate. Incision depth varied according to the amount of power used rather than repetition rate. Higher power and repetitions tended to increase the amount of lateral and deep coagulation rather than cutting efficiency (i.e., the amount of tissue removed). The data suggest that increasing power, repetition rate, and probe diameter does not increase incision width and minimally increases the depth of tissue removal and lateral and deep coagulation.

Once soft tissue excision begins, increasing laser power is of little use. The cutting dynamic is such that once the laser average power is increased to allow cutting, there is no advantage in depth or width in further increasing power. Due to the increase in temperature rise, there is an additional risk of thermal injury at higher laser

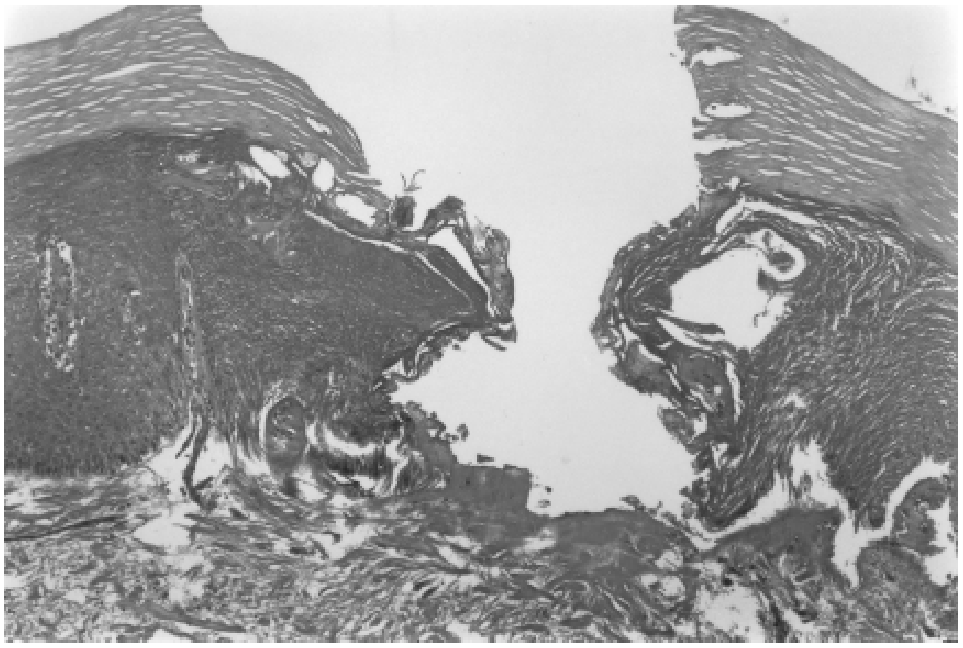

Fig. 3. Photomicrograph of histologic section of gingiva after exposure to 10 W, 50 Hz Nd:YAG laser delivered with a 320-μm-diameter fiberoptic probe (original magnification ×25).

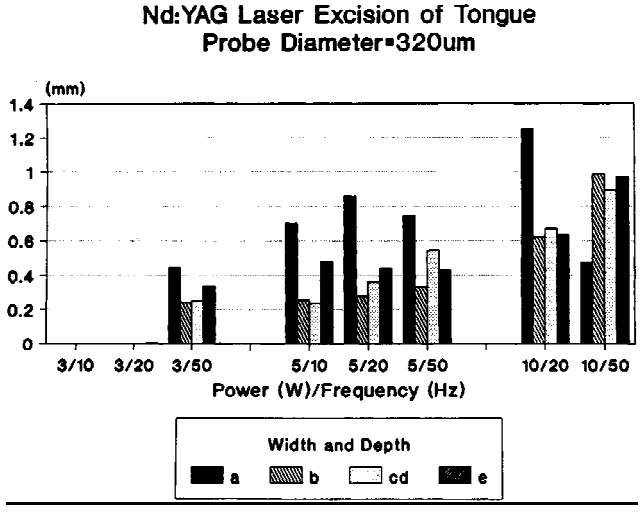

Fig. 4. Measurements of Nd:YAG laser excision of tongue using a 320-μm-diameter probe as a function of power and repetition rate (a = width of tissue removed; b = depth of tissue removed; c,d = lateral coagulation; e = deep coagulation).

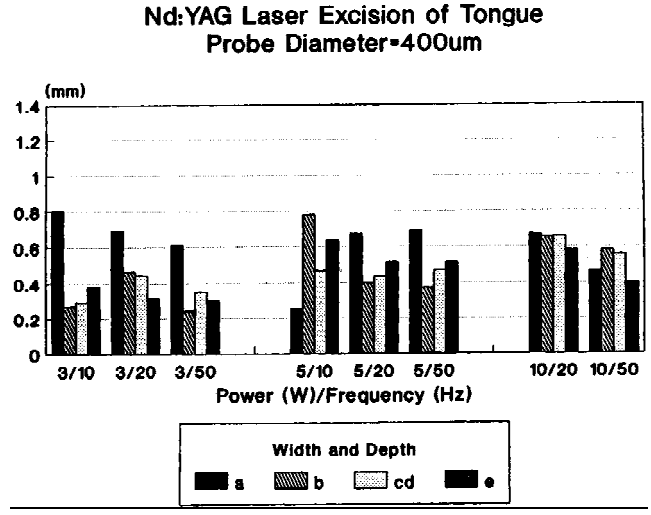

Fig. 5. Measurements of Nd:YAG laser excision of tongue using a 400-μm-diameter probe as a function of power and repetition rate (a = width of tissue removed; b = depth of tissue removed; c,d = lateral coagulation; e = deep coagulation).

powers. In this experiment the thickness of gingiva and oral mucosa was less then 2 mm and was readily excised using the laser parameters described. Human junctional epithelium is 0.25 mm to 1.35 mm long at the epithelial attachment [16] and attached gingiva is 1.25 ± 0.42 mm thick [17], suggesting that surgical procedures aimed at removal of oral epithelium need the lowest laser average power and shortest interaction time for controlled removal and to protect underlying bone. The findings of this study suggest that there is a power setting beyond which no further treat-

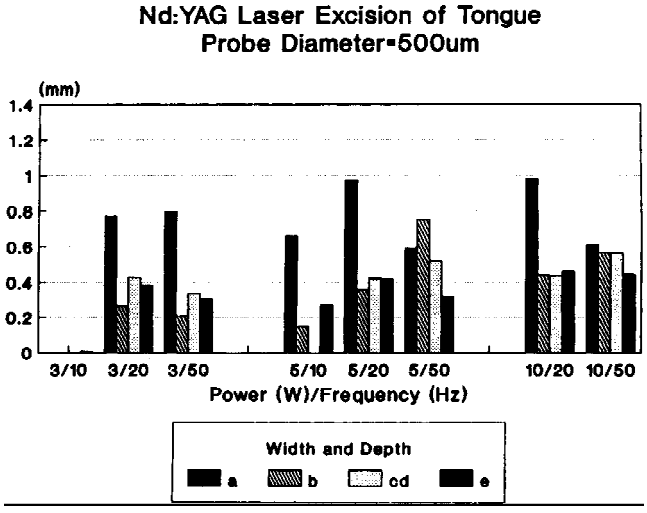

Fig. 6. Measurements of Nd:YAG laser excision of tongue using a 500-μm-diameter probe as a function of power and repetition rate (a = width of tissue removed; b = depth of tissue removed; c,d = lateral coagulation; e = deep coagulation).

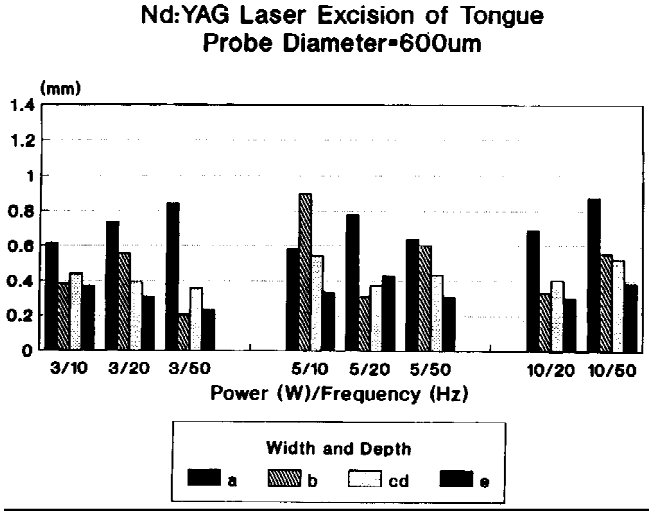

Fig. 7. Measurements of Nd:YAG laser excision of tongue using a 600-μm-diameter probe as a function of power and repetition rate (a = width of tissue removed; b = depth of tissue removed; c,d = lateral coagulation; e = deep coagulation).

ment advantage is gained and unacceptable temperature rises may occur. The clinician must utilize but not exceed the laser parameters which reach the treatment objective of cutting and coagulation of oral soft tissue.

It has been shown that dental pulp temperatures can be elevated to unacceptably high levels [8,9]. This study and previous work from this laboratory have demonstrated that bone temperature can also be increased to unacceptably high levels when high average power lasing of oral tissues is performed [14]. Arcoria and coworkers [18] reported that high-energy combination CO_2 and Nd:YAG lasers can cause substantial necrosis of oral tissues at the surgical site and increase bone temperature. We have found that higher average power, not probe diameter or repetition rate, causes temperature rise in underlying bone. These in vitro findings suggest but do not prove results in living human tissue.

It would appear that 3 W to 5 W at any repetition rate which is sufficient to initiate cutting provides adequate energy density for cutting procedures. This is likely to be sufficiently conservative to protect underlying bone and dental pulp.

Pulsed fiberoptic contact delivered Nd:YAG lasers are the only device with specific indications for cutting and coagulation of human intraoral soft tissue, including the epithelial lining of the free marginal gingiva. Studies of human tissues confirm that lower-power lasing is sufficient to ablate tissue. White et al. [5] successfully treated human subjects with a variety of soft tissue procedures using a pulsed Nd:YAG laser and demonstrated no negative clinical effects on adjacent tissues. Gold and coworkers [4] debrided pocket walls in human subjects using an Nd:YAG laser at 1.25 and 1.75 W, 20 Hz. Histologic specimens showed that 83% of epithelial lining was completely removed with no evidence of necrosis or carbonization of underlying connective tissue. Human subjects tolerated the 2- to 3-min treatments per pocket well, requiring no local anesthesia, with no reported tooth sensitivity or delayed healing. This study further elucidates the effects of various laser parameters on oral soft tissues, confirming that lower wattage is sufficient for human oral tissue lasing.

Our goal was to define the in vitro histologic effects from laser parameters which reach the treatment objective of cutting and coagulation. Findings using a bovine model are consistent with those of Gold and Valardi [4] at lower powers in humans. An advantage of the bovine model is that many laser parameters can be evaluated, including higher powers which would not be utilized in vivo. A limitation of the model is that it is unknown what the healing response would be within and adjacent to the coagulated area. Additionally, some specimens showed histologic artifact from processing and possibly autolysis due to the initial degradation of the bovine tissues. For example, in Figure 3 it is unknown if the separa-

tion of the keritinized epithelium from the underlying connective tissue is a result of scattering of energy along the tissue interface or histologic artifact. This highlights the overall limitation of in vitro studies, because this study design represents a cross section of immediate tissue effects. Living tissues must be used to evaluate changes over time.

Lasers similar to the one utilized in this study have been evaluated for accidental exposure to adjacent bone, enamel, and dentin and also have been compared to electrosurgery [13]. Pulsed fiberoptic delivered Nd:YAG lasers generally do not cause severe carbonization of dental hard tissues at the laser parameters used for cutting soft tissue [14]. CO_2 lasers can cause considerable carbonization of hard tissue even for short interaction times and at low powers [14]. However, the Nd:YAG laser does alter the organic composition of root surfaces, which is of concern for reattachment periodontal procedures [19]. In comparison to electrosurgery, all lasers studied have been shown to produce lower temperature rises in adjacent bone [13]. The temperature rises in bone produced by electrocautery cause necrosis from short accidental contact with the electrosurgical tip [15].

In summary, this study demonstrates a variety of laser parameters for use in cutting and coagulation of intraoral soft tissue using a bovine model. The data demonstrate the initiation of cutting based on power, repetition rate, and probe diameter and the resulting temperature rise to the underlying bone.

The goal of laser surgery is to provide safe and efficient surgical removal of oral soft tissues. Clinical experience suggests some advantages for laser over scalpel surgical procedures for certain incisional and excisional procedures of the oral tissues. Research has consistently demonstrated that laser surgery can be performed safely by using parameters which protect underlying bone and tooth structures. Our investigations indicate that temperature rise in underlying bone is related to increased power. Higher powers caused no increase in cutting efficiency when performed above 3 and 5 W, regardless of repetition rate. However, high powers resulted in unacceptably high temperature rises in bone.

Therefore average power is the key. The mean pooled effects of fiber diameter do not result in more efficient cutting. Clinical application requires thoughtful use of the most efficient parameters with the least potential damage. Our data suggest that the best fiberoptic size is within the mid-sized 320- to 500-μm probes.

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